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USER ASSEMBLY AND SERVICING SYSTEM FOR SPACE STATION
AN EVOLVING ARCHITECTURE APPROACH

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ABSTRACT

On-orbit assembly and servicing of a variety of scientific and applications hardware systems is expected to be one of the Space Station's primary functions. The hardware to be serviced will include the attached payloads resident on the Station, the free-flying satellites and co-orbiting platforms brought to the Station, and the polar orbiting platforms. The requirements for assembly and servicing such a broad spectrum of missions have led to the development of an Assembly and Servicing System Architecture that is composed of a complex array of support elements. This array is comprised of U.S. elements, both Space Station and non-Space Station, and elements provided by Canada to the Space Station Program. For any given servicing or assembly mission, the necessary support elements will be employed in an integrated manner to satisfy the mission-specific needs.

This paper will discuss the structure of the User Assembly and Servicing System Architecture and the manner in which it will evolve throughout the duration of the phased Space Station Program. Particular emphasis will be placed upon the requirements to be accommodated in each phase, and the development of a logical progression of capabilities to meet these requirements.

INTRODUCTION

The Space Station User Assembly and Servicing System has undergone intensive study, revision, and refinement over the last several years. The early reference configuration was used as a basis for the Phase B effort which began in 1985 and culminated in 1987. During Phase B, revisions were made based upon not only the results of the studies and analyses undertaken, but also upon the changes in the overall Space Station configuration. The most important of the latter were the results of the Critical Evaluation Task Force (CETF) and the Phased Program Task Force (PPTF). The phasing of the Space Station Program has caused a substantial change in the Servicing System configuration for the Phase I period.

This paper intends to focus on three things: first, to briefly describe the fundamental objectives and requirements that have been at the foundation of the Servicing System's definition; second, to describe the baselined Servicing System Architecture that resulted from this definition and the phased architecture that results from the Program phasing; and third, to discuss some areas of further study to assess the present Phase I capabilities.

SERVICING OBJECTIVES

There are two fundamental objectives for Space Station servicing. From the very beginning of the Program, it was evident that the servicing of user systems (both attached payloads and visiting free flyers and platforms) was to be an important attribute of the Space Station. Thus, the development of this capability along with the necessary tools, facilities, and procedures became a primary objective. Servicing was also recognized to consist of a broad set of functions including assembly, repair, consumables replenishment, reconfiguration, and storage.

Furthermore, it was realized at an early stage that a Servicing System fully responsive to user needs could not be defined unilaterally, but needed to take into account the capabilities, limitations, and requirements of the core Station. It is because of this and the considerable similarity between the performance of Station maintenance and user servicing, that the objective of optimizing these systems for maximum efficiency was established.

TYPES OF SERVICES REQUIRED

The types of services required can be stated generically as follows:

- Replacement of limited lifetime subsystems and components
- Replacement or repair of failed modules, subsystems, and parts
- Replacement of spacecraft or instrument subsystems to improve performance with new technology (upgrade)
- Replenishment of consumables
- Assembly of observatories, instruments, and attached payloads.

Of particular importance to the science community is the capability for assembly of payloads and instrument systems on-orbit. This service can result in substantial improvements in instrument performance by allowing its design to be optimized for on-orbit operation. Restrictions imposed by the launch vehicle loads and payload envelope can be alleviated by special packaging for launch and assembly on-orbit.

The provision of these services necessarily leads to a particular set of functional capabilities that the Space Station will need to have to satisfy the requirements. While analyzing the detailed scenarios for performing any of these services for a given mission, a "second-order" set of requirements begins to surface. These include items such as staging/storage areas, thermal protection, and contamination protection.

DESIGN REFERENCE MISSIONS FOR CUSTOMER SERVICING

Figure 1 is an abbreviated tabulation of the servicing requirements for a design reference mission set that was used during the Space Station Phase B effort to validate and bound the servicing capabilities as they were being defined. It should be noted that the composition of this mission set has changed since it was first compiled; however, it is less important than the nature of the requirements contained therein. Thus, although a mission set assembled today may well have different constituents, the requirements for the set will remain quite similar.

SERVICING SYSTEM ARCHITECTURE (BASELINE)

The elements that comprise the Servicing System, working together in different combinations, will accomplish the servicing and on-orbit assembly tasks for user systems. The Goddard Space Flight Center (GSFC) has been assigned the responsibility to develop the Servicing System Architecture consistent with the evolving needs of the user community and the Space Station Program. Inherent in this responsibility is the definition of how the various elements will work synergistically to perform the servicing tasks.

The composition of the baselined Space Station Servicing System Architecture is shown in Figure 2. Prior to the phasing of the Space Station Program, all of the elements shown were included in the architecture, even those which are not inherent to the Space Station (such as the National Space Transportation System (NSTS) and the Orbital Maneuvering Vehicle (OMV)). As a result of the Program phasing, some of the elements (either partially or totally) have been deferred to Phase II as shown in the figure. This deferral has resulted in a reduction of the capabilities needed to satisfy certain requirements.

CAPABILITIES PROVIDED BY THE PHASED ARCHITECTURE

Figure 3 provides a summary of the servicing capabilities provided by the current Phase I Space Station configuration and those that are to be added in the post-Phase I period (Phase II). As can be seen in the figure, Phase I servicing will essentially be limited to in situ servicing tasks because the capability to provide the support systems and the means for environmental protection are deferred to Phase II. Using attached payloads as an example, only those servicing functions that can be performed without these requirements can be accomplished. Likewise, the replenishment of fluids (fuels and cryogens) will not be accommodated until Phase II.

Additionally, servicing missions will be adversely impacted by the lack of a staging/storage area in Phase I.

MAJOR ELEMENTS OF THE BASELINE SERVICING SYSTEM ARCHITECTURE

As shown in Figure 2, the Servicing System is comprised of 13 support elements. Four of the major elements and their characteristics are as follows:

- Intravehicular Servicing Capability - This capability, shown in Figure 4, is centered around an Intravehicular Activity (IVA) Workbench inside the pressurized volume of the Space Station. The GSFC is responsible for defining the requirements for this workbench from a user perspective, while the Marshall Space Flight Center (MSFC) is responsible for its design and development. This workbench will have the capability to provide a clean environment for servicing instruments, ORUs, and other customer hardware elements that are sufficiently small to be transported through the airlock hatch. The bench will be equipped with tools to support component replacement, printed circuit board changeout, and other limited repair and checkout tasks.

- Flight Telerobotic Servicer - The Flight Telerobotic Servicer (FTS), illustrated conceptually in Figure 5, also is being developed under the direction of the GSFC. This system is intended to be used to replace or reduce the need for hazardous and costly Extravehicular Activity (EVA) in the performance of many servicing tasks. At the beginning of the Space Station Program, the FTS will be employed to assist in the assembly of the Station. In its early configurations, it will be teleoperated from a control console located either on the ground, in the STS cabin, or in one of the pressurized modules. As the necessary technologies mature, the FTS will evolve to increasing levels of autonomy. The FTS Project is currently nearing completion of its Phase B definition period from which more detailed concepts will emerge.

- Mobile Servicing Center - The Mobile Servicing Center (MSC), depicted in Figure 6, will be provided to the Space Station Program by Canada. In conjunction with the U.S. Mobile Transporter (MT), it will provide the capability to transport payloads, EVA crew, servicing and maintenance hardware, and the FTS to various locations on the Station truss. Additionally, the MSC is expected to make possible the in situ servicing of attached payloads and Station systems when the tasks to be performed require no environmental protection. The capabilities of the MSC will be phased such that initial elements are deployed on the Station over several assembly flights during Phase I, and the remainder added during Phase II. The Special Purpose Dextrous Manipulator (SPDM), attached to the manipulator in Figure 6, is also supplied by Canada.

- Space Station Servicing Facility - The configuration of the Servicing Facility and its location on the Space Station truss is shown in Figure 7. The facility is shown in its open configuration with the Hubble Space Telescope (HST) berthed in preparation for servicing. During the actual servicing operation, the facility would be fully closed around the HST to protect it from contamination and damaging solar impingement and thermal extremes. The facility consists of a large deployable enclosure mounted on a track structure that contains several separate enclosed storage areas, which provide the capability to accommodate instruments, ORUs, tools, the FTS, the OMV, and other servicing related equipment in a protected environment. As the figure shows, the facility includes a dedicated manipulator to ease operations within the enclosure. The servicing support equipment contained in the facility will allow servicing missions to be performed by EVA, the FTS, or by a suitable combination of both. As shown in Figure 2, the Servicing Facility is currently designated for deployment in the Phase II period.

SERVICING FACILITY INCREMENTAL ASSEMBLY

The Servicing Facility, as defined during Phase B of the Space Station Program, will be designed in a modular fashion so that it could be manifested on the NSTS in either one flight or divided to share the Orbiter's payload bay with other hardware on three flights. The latter approach allows an incremental buildup of servicing capability that offers considerable flexibility by providing capability as it is needed. Figure 8 depicts these three increments and shows a tabulation of the types of servicing functions and missions that can be accommodated with each one. Due to the design concept for the facility, a further breakdown is also possible. For example, only one or two of the three storage areas shown under the "Group 1" configuration could be deployed initially, providing a reduced capability that could be augmented later. Although the "Group 2" configuration is only about half the size of the full Servicing Facility, it could provide a significant capability to service attached payloads and small Explorer class free flyers as well as the necessary FTS and OMV accommodations.

ATTACHED PAYLOAD AND FREE FLYER SERVICING REQUIREMENTS MATRICES

Figures 9 and 10 provide matrix tabulations of the servicing requirements of likely candidate attached payloads and free flyers. The parameters enclosed by a box in Figure 8 drive the need for environmental protection of the payload during servicing and the need for a protected storage location for servicing hardware. As shown in the tables, the thermal constraints for all missions are stringent and can be expected to apply to most other missions that might be added to the list in the future. Therefore, it should be noted that the composition of the payload set is less important than the scope of the parameters. This is equally true for the contamination control requirements. Efforts are currently underway to more clearly define the contamination control and storage volume requirements of a smaller set of payloads that is considered likely for the early Station phase. With a more definitized set of requirements, the Program will be able to plan the phased buildup of the servicing capabilities in an optimized manner.

ADDITIONAL AREAS OF STUDY FOR PHASE I

As mentioned above, further study is underway to examine the Phase I Space Station servicing capabilities with respect to a definitized set of phased requirements. The areas being investigated are as follows:

- Storage/Staging Accommodations - In developing and analyzing scenarios for specific servicing missions, a need for this type of capability has become evident. The focus of study in this area is to validate and quantify the requirement.

- Servicing and Assembly of Payloads Having Thermal, Contamination, or Solar Impingement Sensitivities - Using a realistic set of near-term payloads, their requirements will be documented and quantified.

- FTS Accommodations - Since the FTS is designated to be a part of the Space Station from First Element Launch, its accommodation requirements will be definitized and concepts for their satisfaction will be developed.

- EVA Efficiency - The requirements for maximized efficiency in the use of EVA for servicing activities will be studied. Factors to be included are support equipment, lighting conditions, and time required for "setup" and "teardown" of the worksite.

- Accommodation of Contingencies - The inherent flexibility of the Servicing System will determine its ability to accommodate a variety of contingency situations. Potential contingencies during servicing, maintenance, assembly, and loading/unloading the NSTS Orbiter will be considered.

CONCLUSION

The Space Station Servicing System has undergone a considerable amount of evolutionary change even in its Phase B definition period. As the development phase of the Program progresses, it is reasonable to expect that this evolution will continue, but with decreasing magnitude. The end result will be a Servicing System configuration that ultimately optimizes the utilization of the Space Station as a servicing base for the broad user community. The key to this optimization is the continuing evaluation of the user requirements and the provision of servicing capabilities that are commensurate with them through each phase of the Space Station Program.

MISSION	SERVICING REQUIREMENTS
FTS	STORAGE LOCATION AND ACCOMMODATIONS, MAINTENANCE
ASTROMAG	CRYO REPLENISHMENT, ASSEMBLY, INSTRUMENT CHANGEOUT
SOT/HRSO	ORU REPLACEMENT, FILM CANNISTER CHANGEOUT
STO	ORU REPLACEMENT, INSTRUMENT CHANGEOUT, CANNISTER REPLACEMENT
EXPLORER (SMM CLASS)	INSTRUMENT CHANGEOUT, ORU REPLACEMENT
HST	ORU REPLACEMENT, INSTRUMENT CHANGEOUT, CRYO REPLENISHMENT
GRO	ORU REPLACEMENT, HYDRAZINE REFUELING
AXAF	ORU REPLACEMENT, INSTRUMENT CHANGEOUT, CRYO REPLENISHMENT
SIRTF	ORU REPLACEMENT, INSTRUMENT CHANGEOUT, CRYO REPLENISHMENT
SPARTAN	PAYLOAD CHANGEOUT, HYDRAZINE REFUELING
OMV	PROPULSION MODULE CHANGEOUT, STORAGE LOCATION AND ACCOMMODATIONS FOR OMV AND MODULE, ORU REPLACEMENT

Figure 1. Design Reference Missions for Customer Servicing

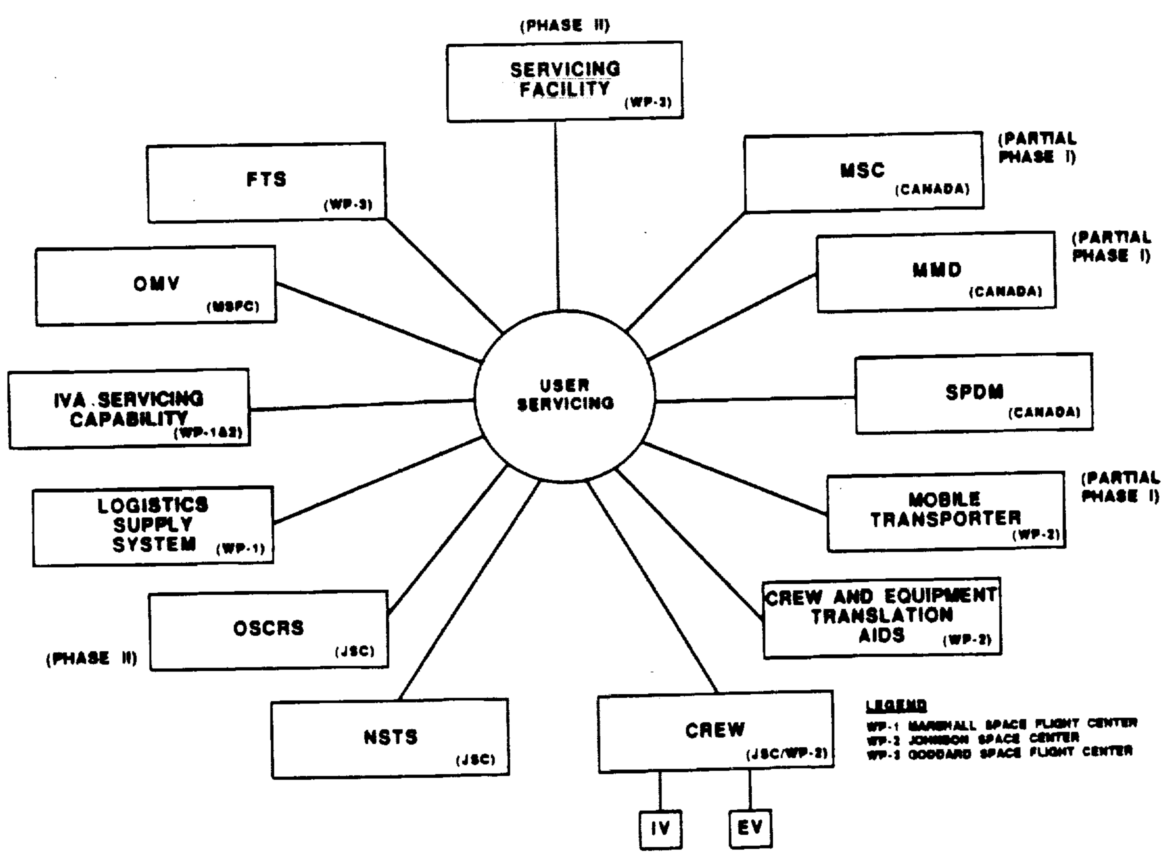

Figure 2. Servicing System Architecture

PHASE 1

- TRANSPORTATION: ON SPACE STATION TRUSS (MT/MSC); TO/FROM OTHER ORBITS (OMV); GROUND TO ORBIT AND RETURN (STS)
- SERVICING ATTACHED PAYLOADS IN SITU (MT/MSC/FTS/SPDM/CREW)
- SERVICING POLAR PLATFORMS IN SITU (STS/OMV/FTS); ELV OPTION UNDER STUDY
- IVA REPAIR OF ORUs (IVA WORKBENCH)

PHASE 2

- SERVICING ATTACHED PAYLOADS, FREE FLYERS, AND CO-ORBITING PLATFORMS IN THERMAL AND CONTAMINATION-CONTROLLED ENVIRONMENT (SERVICING FACILITY/FTS/CREW)
- REPLENISHMENT OF PROPULSION AND CRYOGENIC SYSTEMS (SERVICING FACILITY/FTS/OSCRS)
- PROTECTED STORAGE FOR PAYLOADS, INSTRUMENTS, AND ORUs AWAITING ASSEMBLY, INSTALLATION, REPAIR, OR RETURN TO GROUND (SERVICING FACILITY)
- ACCOMMODATIONS FOR OMV AND FTS (SERVICING FACILTY)

Figure 3. Capabilities Provided by Phased Architecture

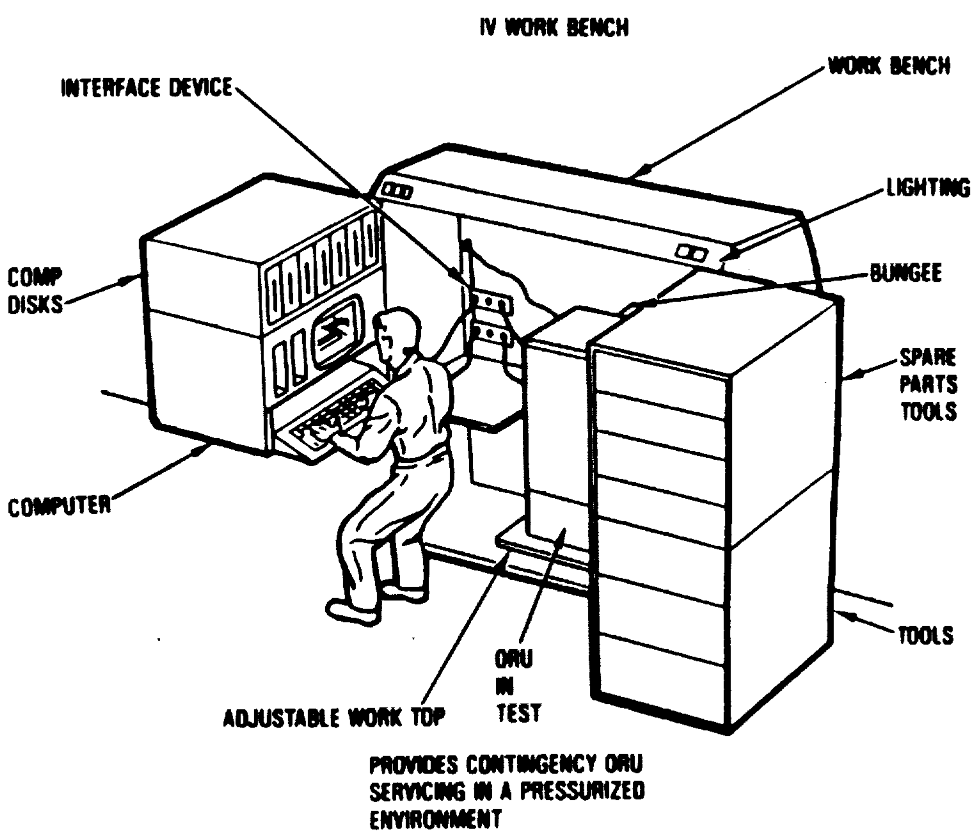

Figure 4. IVA Servicing Workbench Concept

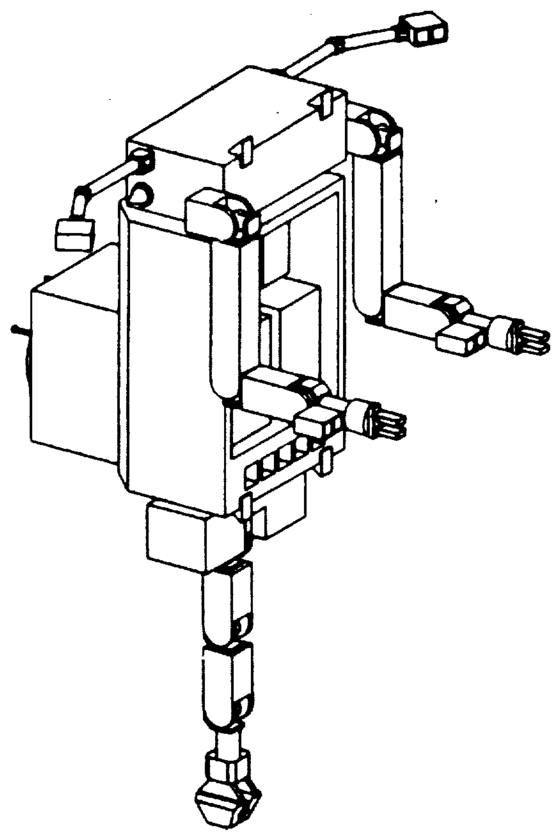

Figure 5. Flight Telerobotic Servicer Concept

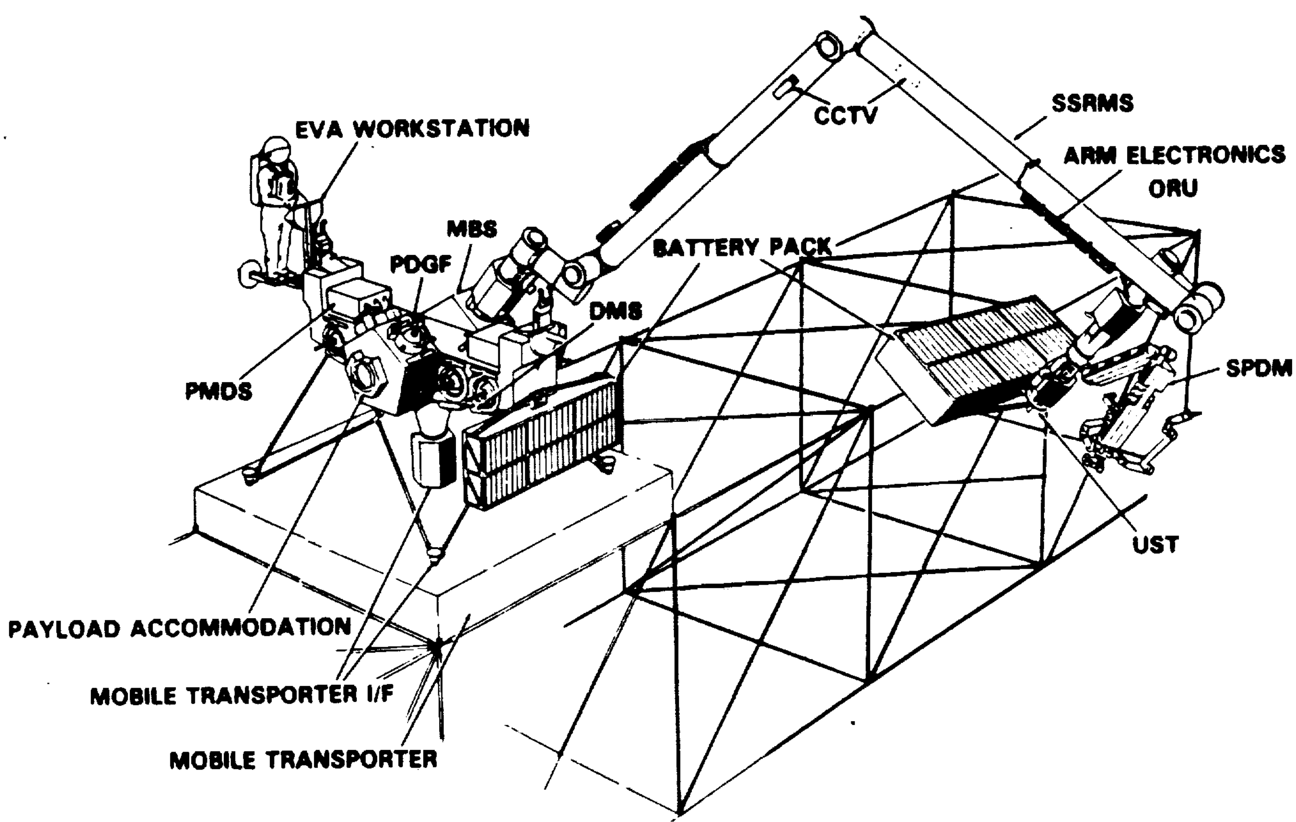

Figure 6. Mobile Servicing Center

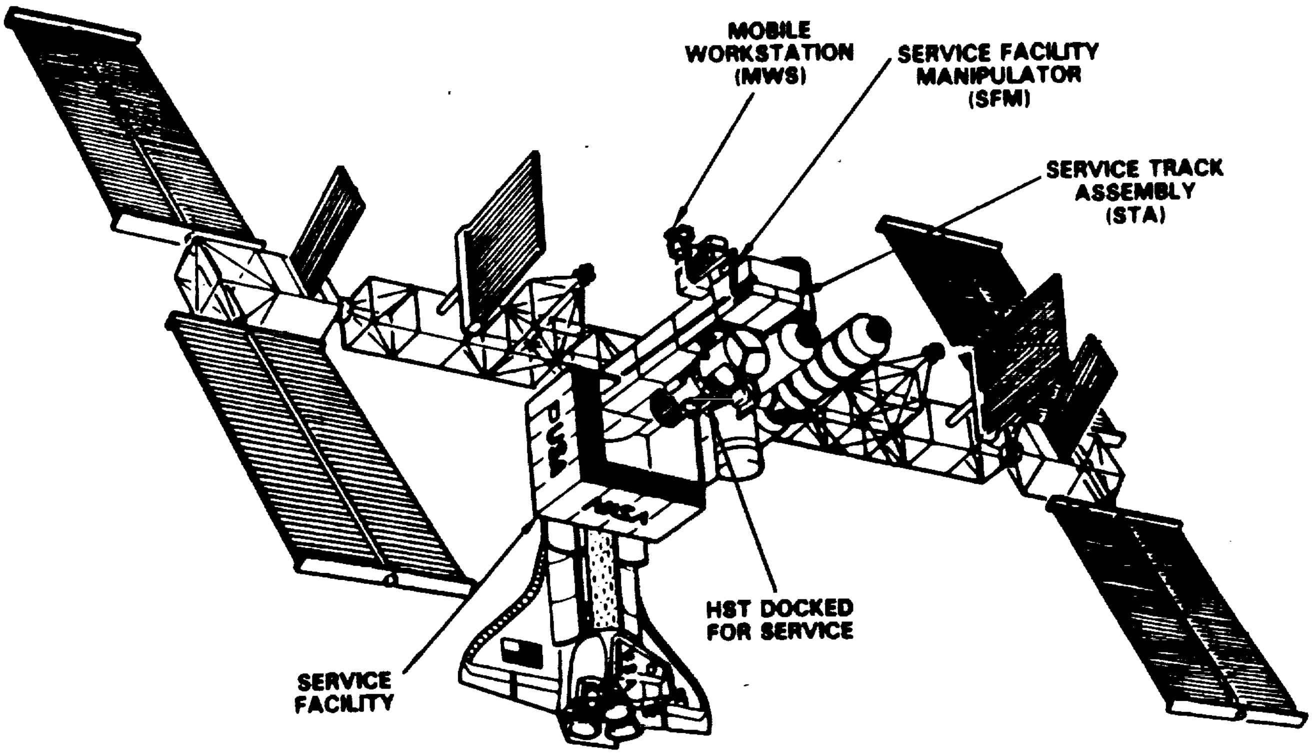

Figure 7. Space Station Servicing Facility Configuration

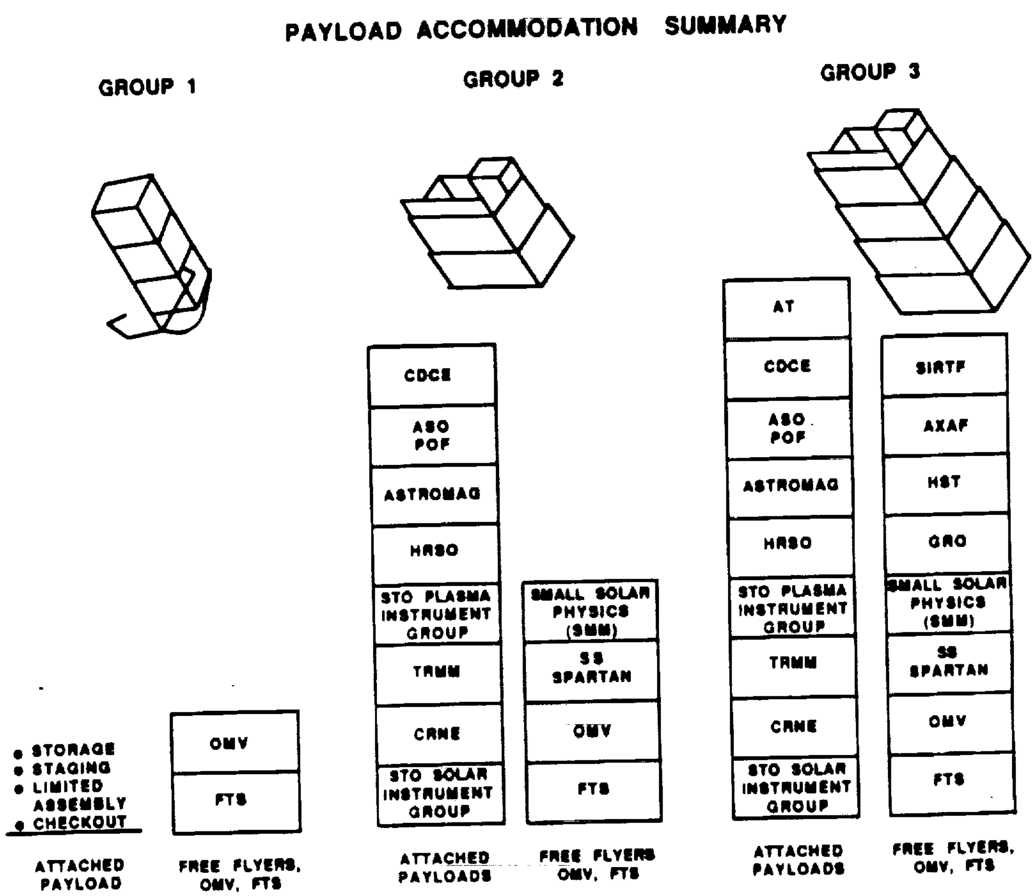

Figure 8. Servicing Facility Incremental Assembly

GROUP 1 - PAYLOAD ACCOMMODATIONS

REQUIREMENT	ASTROMAG	STO SOLAR INSTRUMENT GROUP	AT	CRME	CDCE	TRMM	ASO/POF	STO PLASMA INSTRUMENT GROUP
ENVELOPE	Length - 3.3 m Diam - 4.8 m	Length - 8 m Diam - 1.5 m	Length - 21.40 m Diam - 4 m	Length - 3.3 m Diam - 4.8 m	Length - 3 m Diam - 3 m	Length - 3.5 m Diam - 2 m	Length - 6.25 m (retracted) Diam - 4.3 m	Length - 4 m Diam - 3 m
MASS	6,000 kg	5,921 kg	5700 kg	2,500 kg	1,600 kg	425 kg	2700 kg	5,921 kg
THERMAL CONTROL	-10°C to +30°C	+10°C to +30°C	-20°C to +50°C	0°C to +40°C	-10°C to +40°C	0°C to +30°C	+17.7°C to +24.3°C	+10°C to +30°C
CONTAMINATION CONTROL	None	Precautions Required	Stringent	None	Stringent	Precautions Required	Stringent	Precautions Required
POWER	1.5 kW	1.2 kW	1.5 kW	0.4 kW	1.2 kW	0.3 kW	0.8 kW	1.3 kW
ATTACHMENT	TBD	SIA/PIA STS Trunnions	STS Trunnions	STS Trunnions	STS Trunnions	STS Trunnions	STS Trunnions	SIA/PIA STS Trunnions
STORAGE VOLUME	ORUs, Carrier, Consumables	ORU Carrier, ORUs, FSE, Consumables	ORU Carrier, ORUs, FSE	Consumables (360 kg); Carrier (165 kg)	ORU Carrier, ORUs	ORU Carrier, ORUs, FSE	ORU Carrier, ORUs, FSE	ORU Carrier, ORUs, FSE
ASSEMBLY	YES	YES	YES	NO	YES	NO	NO	YES
ORU REPLACEMENT	YES	YES	YES	NO	YES	YES	YES	YES
INSTRUMENT CHANGEOUT	YES	YES	YES	NO	NO	YES	YES	YES
FLUID REPLENISHMENT	YES (Cryogens)	YES	NO	YES	NO	NO	NO	YES
DATA (Hardline)	500 bps	4620 kbps	1750 kbps	100 kbps	.1 kbps	650 kbps	1000 kbps	5150 kbps
SERVICE INTERVAL	1 year	1 to 2 years	5 years	1 year	3 months	1 year	5 years	1 to 2 years

☐ Indicates mission not accommodated

SOURCE: Customer Servicing Requirements Data Book, JSC 30222

Figure 9. Attached Payload Servicing Requirements Matrix

GROUP 1 - ACCOMMODATIONS

REQUIREMENT	HST	GRO	SS SPARTAN	SMALL SOLAR PHYSICS (SMM)	AXAF	SIRTF	OMV	FTS
ENVELOPE	Length - 13.1 m Diam - 4.3 m	Length - 9.6 m Diam - 21.5 m	Length - 2.5 m Diam - 4.6 m	Length - 5.0 m Diam - 2.8 m	Length - 15.0 m Diam - 4.6 m	Length - 10.9 m Diam - 4.1 m	Length - 1.1 m Diam - 4.5 m	Length - 1.06 m Width - 91 m Height - 2.13 m (estimates)
MASS	11,300 kg	15,000 kg	4,300 kg	3,000 kg	13,000 kg	4,700 kg	5,776 kg	600 kg (estimate)
THERMAL CONTROL	+20°C to +30°C	-10°C to +35°C	+7°C to +24°C	-5°C to +45°C	5°C to +40°C	-23°C to +27°C	175 W contingency power	-5°C to +10°C (Battery storage)
CONTAMINATION CONTROL	Stringent	Minimal	Mission dependent	Mission dependent	Less stringent	Stringent	Minimal	None
POWER	2.3 kW	2.0 kW	0.7 kW	0.7 kW	2.8 kW	0.4 kW + TBD COP (2 kW)	0.7 kW	.6 kW average 2 kW peak
ATTACHMENT	STS Trunnions FSS berthing pins	STS Trunnions FSS berthing pins	STS Trunnions	STS Trunnions FSS berthing pins	STS Trunnions FSS berthing pins	STS Trunnions	STS Trunnions	Trunnions
STORAGE VOLUME	1 pallet - ORUs	Length - 1.8 m Diam - 4.3 m	Length - 2.5 m Diam - 4.6 m	ORU; Carrier	1 pallet - ORUs	1 pallet - ORUs 1 pallet - fluids	Length - 1.1 m Diam - 4.5 m	ORUs; Tools
ORU REPLACEMENT	YES	YES	YES	YES	YES	YES	YES	YES
INSTRUMENT CHANGEOUT	YES	NO	YES	YES	YES	NO	NO	NO
FLUID REPLENISHMENT	Not at IOC	1800 kg of hydrazine	375 kg of hydrazine	NO	Cryogens (TBD)	8800 liters of SHe	Hydrazine-634 kgs Bi-props - Module Replacement	NO
DATA	Hardline - none RF - 1.024 Mbps	Hardline-512 kbps RF - 512 kbps	Hardline-300 kbps RF - 300 kbps	Hardline-512 kbps RF - 512 kbps	Hardline - 48 kbps RF - 64 kbps	Hardline 512-kbps RF - TBD	Hardline - TBD RF - 1.44 Mbps	Storage - 64 kbps Operations-10 kbps
SERVICE INTERVAL	3 years	2 years	1 to 3 months	3 years	3 years	2 years	Mission dependent	TBD

☐ Indicates mission requirements not accommodated

SOURCE: Customer Servicing Requirements
Data Book, JSC 30222

Figure 10. Servicing Requirements Matrix (Free Flyers, OMV, FTS)

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